On long-term behavior of North-South Asymmetry of Solar Phenomena

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Abstract

In the solar North-South Asymmetry(NSA) study we have used sunspots data and flare index data for period 6-24 (years 1821-2015) solar cycles. Earlier Verma (1992) reported long-term cyclic period 11-12 solar cycles in NSA and also predicted that the NSA of solar activity phenomena during solar cycles 21, 22, 23 and 24 will be southern dominated and the NSA will shift to northern hemisphere in solar cycle 25. The present study shows that the NSA indices during solar cycles 22 and 23 are southern dominated as predicted by Verma (1992). The initial estimate of NSA for years 2008-2015 of solar cycle 24th is showing southern domination and confirm the result of Verma(1992). The 11 solar cycle's periodic behavior of the Sun may be related to internal structure of the Sun.

Bell (1962, Smithsonian Contr. Astrophys., 5, 187)

The first real study of NSA was done by Bell in 1962.

- **Bell (1962) used sunspots group data to study NSA for period solar cycles 8-19 as shown in Figure A.**
- **Solar cycles Dominance**
- **08-09 Northern**
- **10-13 Southern**
- **14-19 Northern**

From Figure B is plot for SC 09-18 based on GMS gives mixed results as shown in Figure B...

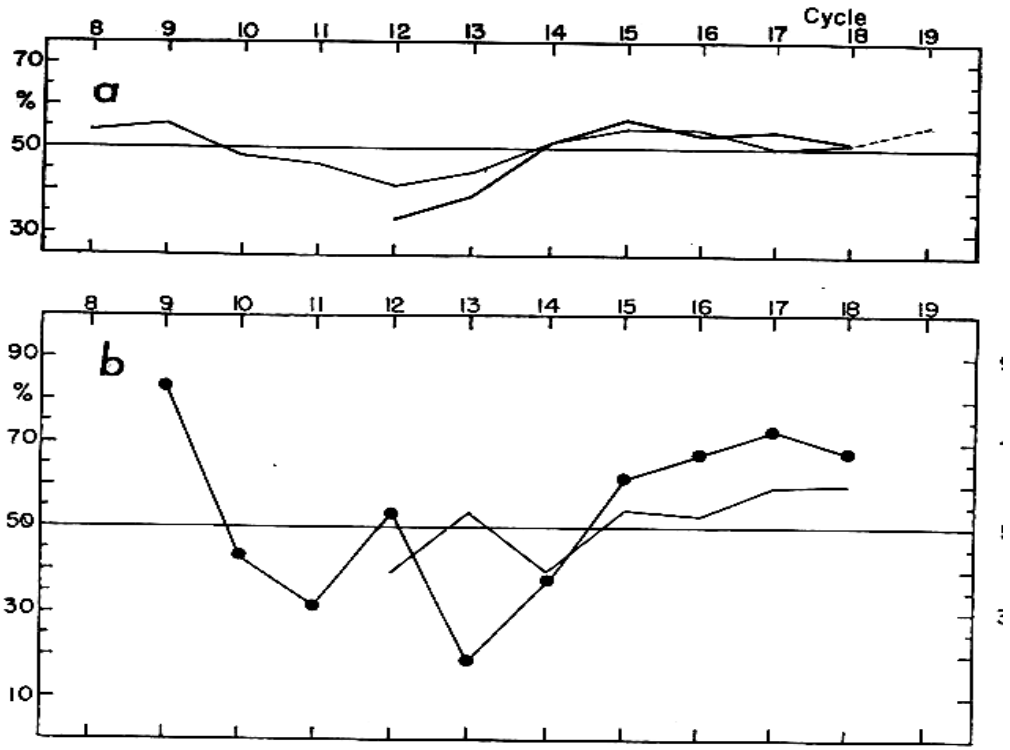


FIGURE 1.—Percentage of spot activity occurring in the northern solar hemisphere in each sunspot cycle from 8 to 19. *a*, Heavy line indicates great ($A \geq 500$) sunspot groups; thin line, total spottedness. *b*, Percentage of great (●——●) and small (——) geomagnetic storms attributed to northern spot groups.

Reid(1968,SP,5,207),Howard(1974,SP,35,59),Hansen & Hansen (1975, SP,38,59), Roy (1977, Solar Phys., 52, 53) and Swinson et al (1986,SP,106,35).

Authors	Data	Period	Dominance
Reid	SF	58-65	North
Howard	MF	67-73	North
Han &Hans	FI	64-75	North
Roy	SF	62-74	North
Swinson	SA,SN	74-84	North

Roy(1977)studied NSA using major solar flares, sunspot magnetic classes and sunspot areas data for period 1960-1964 (19thSC) and 1965-1975(20thSC).Roy's study also show that NSA favor northern hemisphere during above period and increases strikingly with importance of events.

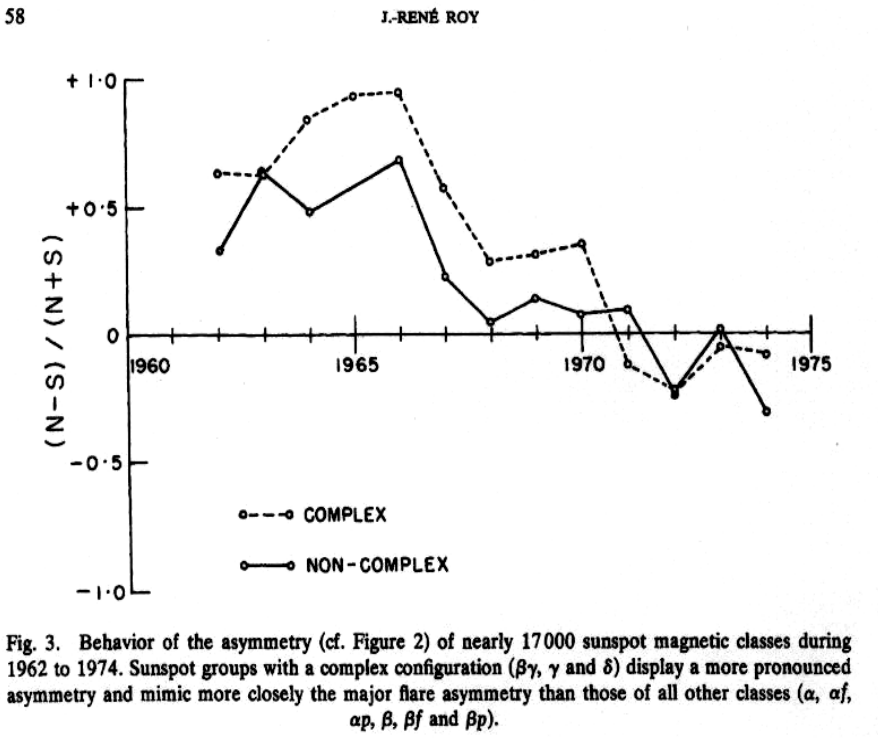


Fig. 3. Behavior of the asymmetry (cf. Figure 2) of nearly 17000 sunspot magnetic classes during 1962 to 1974. Sunspot groups with a complex configuration ($\beta\gamma$, γ and δ) display a more pronounced asymmetry and mimic more closely the major flare asymmetry than those of all other classes (α, αf, αp, β, βf and βp).

Verma, V. K.(1987, SP,114, 185)

- **Verma(1987) studied using data of major flares, type II radio bursts, White Light Flares(WLF) found that NSA favor northern hemisphere during solar cycles 19 and 20 and also found that NSA favors southern hemisphere during solar cycle 21 for type II, WLF, SGR, HXR and CMEs. The data used in study shown in side Table.**

TABLE I : Number of various solar activity events recorded in solar cycles 19, 20 and 21.

Various solar activity events	Number of events in solar cycles 19 N	19 S	20 N	20 S	21 N	21 S	References/Source of data.
Major flares	407	195	589	330	-	-	Dodson and Hedeman (1971, 75)
Type II radio bursts	122	42	223	137	256	350	Dodson and Hedeman (1971, 75, 81) and Solar Geophysical Data (1980- 1987)
White light flares	18	8	22	17	8	17	Neidig and Cliver (1983), Rust et al. (1986) and Huang et al. (1986)
Solar gamma ray bursts	-	-	-	-	40	51	Rieger et al. (1983) Yoshimori (1985)
HXR bursts	-	-	-	-	140	175	Hinotori satellite data
CME's events	-	-	-	-	16	21	Sheeley et al (1984)

N : Northern hemisphere, S : Southern hemisphere.

Verma (1987, Solar Phys., 114,185)

Verma(1987) studied using data of major flares, type II radio bursts, WLF found that NSA favor northern hemisphere during solar cycles 19 and 20 and also found that NSA favors southern hemisphere during solar cycle 21 for type II, WLF, SGR, HXR and CMEs as shown in Figure 1. This was the first paper to report NSA southern hemisphere dominance during solar cycle 21.

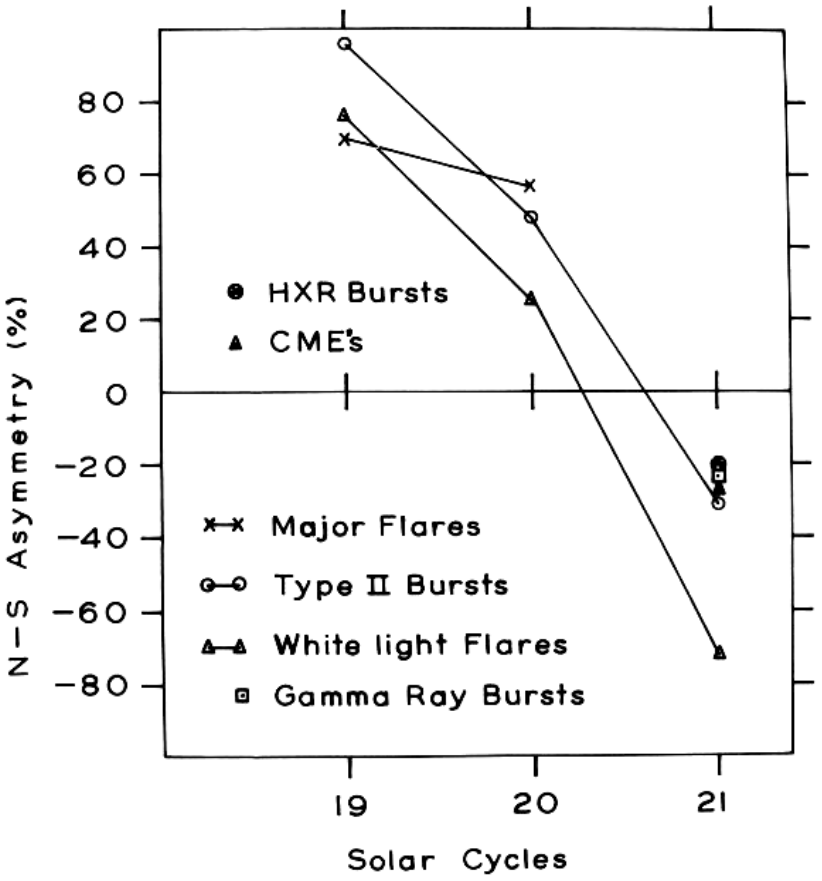


Fig. 1 A plot of various types of solar activity events in solar cycles 19,20 and 21 versus N-S asymmetry index.

Verma (1992, ASP, 27, 429)

Verma(1992) studied NSA of Sunspot Area, Sunspot counts, sunspot groups, solar flares, Major flares, Gamma ray flares and H-alpha flares data for time interval 1832-1990 (Solar Cycles 08-22) as shown in side Table 1. The source of data is also shown in side Table.

TABLE I Types of Solar Phenomena and Their References

Solar Phenomena	Period	References
Sunspot areas	1832-1871	Wolbach (1962)
	1874-1954	Janes (1955)
	1955-1976	Annals Royal Greenwich Observatory, England
Sunspot counts	1833-1877	Newton and Milson (1955)
Sunspot groups	1954-1986	Okten (1989)
Solar flares	1936-1944	Behr and Siedentopf (1952)
	1945-1955	Smith and Smith (1965)
Major flares	1955-1979	Dodson and Hedeman (1971, 1975, 1981)
Gamma ray flares	1980-1986	Vestrand *et al.* (1987)
H-alpha flares	1987-1990	Solar Geophys. Data (1988-1991)

Verma (1992, ASPCS, 27,429)

Verma(1992) studied the NSA of various solar phenomena as shown in side Figure 1 for period 8 to 22 solar cycles. This Figure show that the NSA may have a period of 12 solar cycles (about 110 years). Verma (1992) also reported that the NSA will favor southern hemisphere during 22nd , 23rd and 24th Solar cycles and shift to northern hemisphere during solar cycle 25.

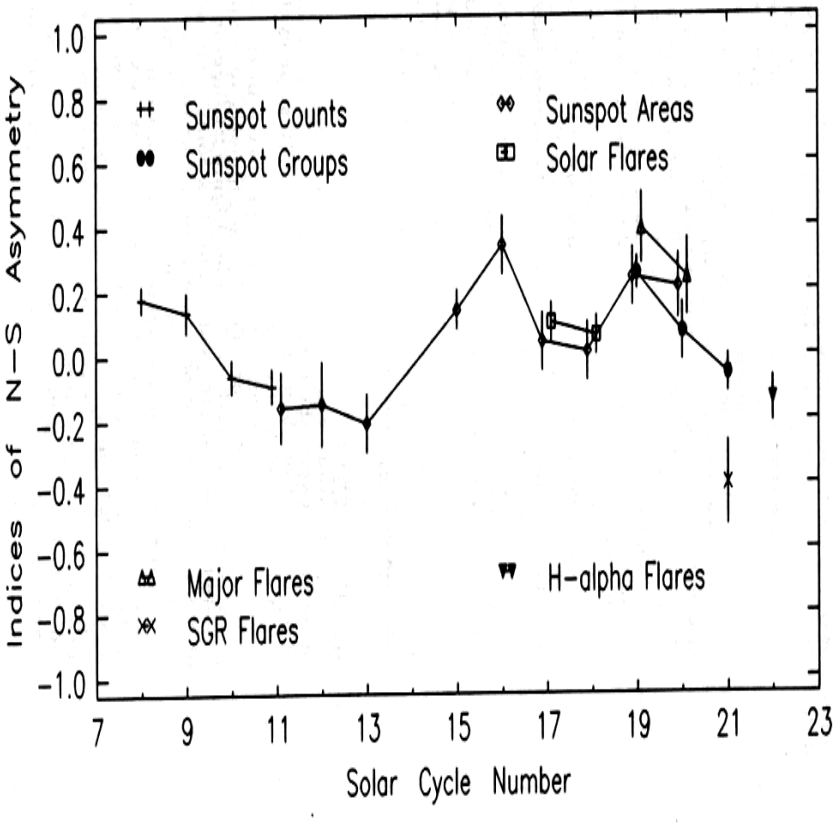


Fig. 1 Plot of N-S asymmetry of seven solar phenomena versus solar cycle number.

Verma (1992, ASP, 27, 429)

- **Verma (1992) study of data using e power spectrum analysis is also carried out of averages of NSA data for period 159 years which includes spot area, spot counts, spot groups and H-alpha flares data and found a period 106 years along with other period. This period is close to 110 years period obtained graphically as shown in previous slide.**

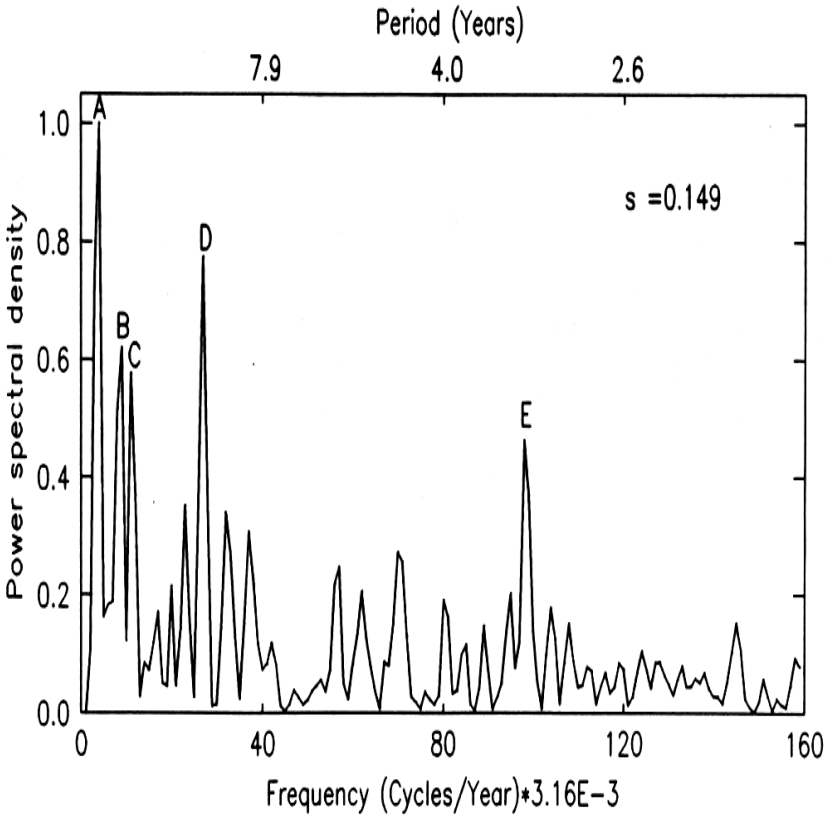


Fig. 2 Plot of power psectral density of N-S asymmetry data versus frequency (cycles/year).

Verma (1993, APJ,403, 797)

Verma(1993) studied NSA of Sunspot Area, Sunspot counts, sunspot groups, solar flares, Major flares, Gamma ray flares and H-alpha flares for time interval 1832-1990 (Solar Cycles 08-22) as shown in side Table 2.

TABLE 2

SUMMARY OF THE PREVIOUS STUDIES OF NORTH-SOUTH ASYMMETRIES

AUTHORS	DATA	TIME INTERVAL		PREFERRED HEMISPHERE
		YEARS	SOLAR CYCLES	
Bell 1961	Major flares	1937–1959	17–18	North
Bell 1962	Sunspot groups	1837–1859	8–9	North
	Sunspot groups	1860–1904	10–13	South
	Sunspot groups	1905–1956	14–18	North
Reid 1968	Solar flares	1958–1965	19	North
Hansen & Hansen 1975	Filaments	1964–1974	20	North-South
Howard 1974	Magnetic field strength	1967–1973	20	North
Roy 1977	White light flares	1859–1974	10–20	North
	Major flares	1962–1974	19–20	North
	Sunspot area	1955–1974	19–20	North
Verma 1987	Major flares	1955–1965	19	North
	Major flares	1966–1975	20	North
	Type II radio bursts	1955–1965	19	North
	Type II radio bursts	1966–1975	20	North
	Type II radio bursts	1976–1986	21	South
	White light flares	1955–1965	19	North
	White light flares	1966–1975	20	North
	White light flares	1976–1986	21	South
	HXR bursts	1981–1982	21	South
	CME events	1979–1982	21	South
	SGR bursts	1980–1981	21	South
Bai 1990	Major flares	1955–1964	19	North
	Major flares	1965–1975	20	North
	Major flares	1976–1986	21	Equal
	Major flares	1986–1990	22	South

Verma(1993, APJ,403, 797)

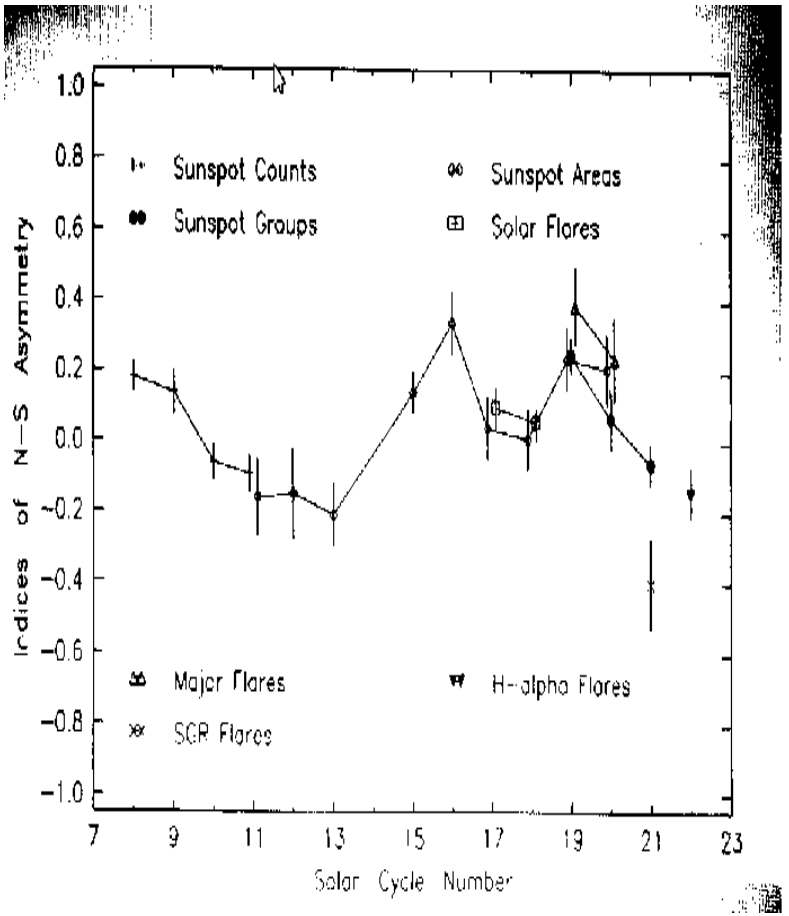
- **Verma(1993) using various solar activity data as shown in side Table. Verma(1993) used sunspot area, sunspot counts, sunspot groups, solar flares, major flares, gamma ray flares and H-alpha flares for different time period as shown in Table with respective references.**

TABLE I Types of Solar Phenomena and Their References

Solar Phenomena	Period	References
Sunspot areas	1832-1871	Wolbach (1962)
	1874-1954	Janes (1955)
	1955-1976	Annals Royal Greenwich Observatory, England
Sunspot counts	1833-1877	Newton and Milson (1955)
Sunspot groups	1954-1986	Okten (1989)
Solar flares	1936-1944	Behr and Siedentopf (1952)
	1945-1955	Smith and Smith (1965)
Major flares	1955-1979	Dodson and Hedeman (1971, 1975, 1981)
Gamma ray flares	1980-1986	Vestrand *et al.* (1987)
H-alpha flares	1987-1990	Solar Geophys. Data (1988-1991)

Verma (1993, APJ, 403, 767)

Verma(1993) investigated NSA of various solar phenomena as shown in side Figure. We plotted a figure between Solar Cycle Number and NSA index with error bars as shown in Figure. Verma(1993) concluded from analysis that there may be NSA periodicity of 12 solar cycles.



Atac and Ozguc(1996, Solar Phys, 166, 201)

- **Atac and Ozguc calculated solar flare index daily, monthly and annually for period 1936-1993 and they also calculated NSA solar flare index for 17-22 solar cycles as shown in slide which shows the dominance of southern hemisphere during cycle 21-22. This result support & confirm the earlier work of Verma (1992).**

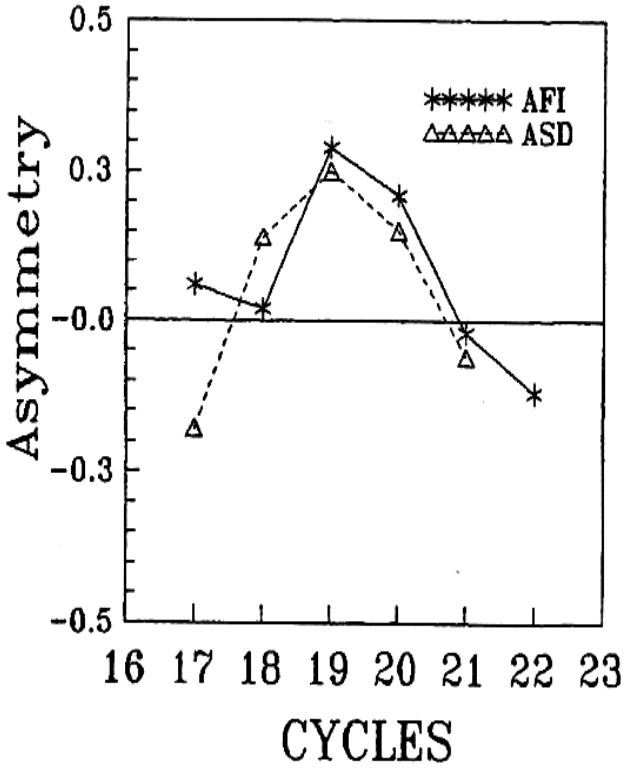


Fig. 3. Plot of N–S asymmetry of flare index (AFI) and sudden disappearances (ASD) versus solar cycles. (ASD values adopted from Vizoso and Ballester, 1987.)

Verma (2000, Solar Phys., 194, 87)

Verma (2000) downloaded active filaments data for period 1957-1958 from NGDC website. Verma (2000) estimated NSA indices for solar active prominences(SAP) for period years 1957-1998 as shown in side figure . The plot of the Year versus yearly NSA Indices is shown in the side Figure.

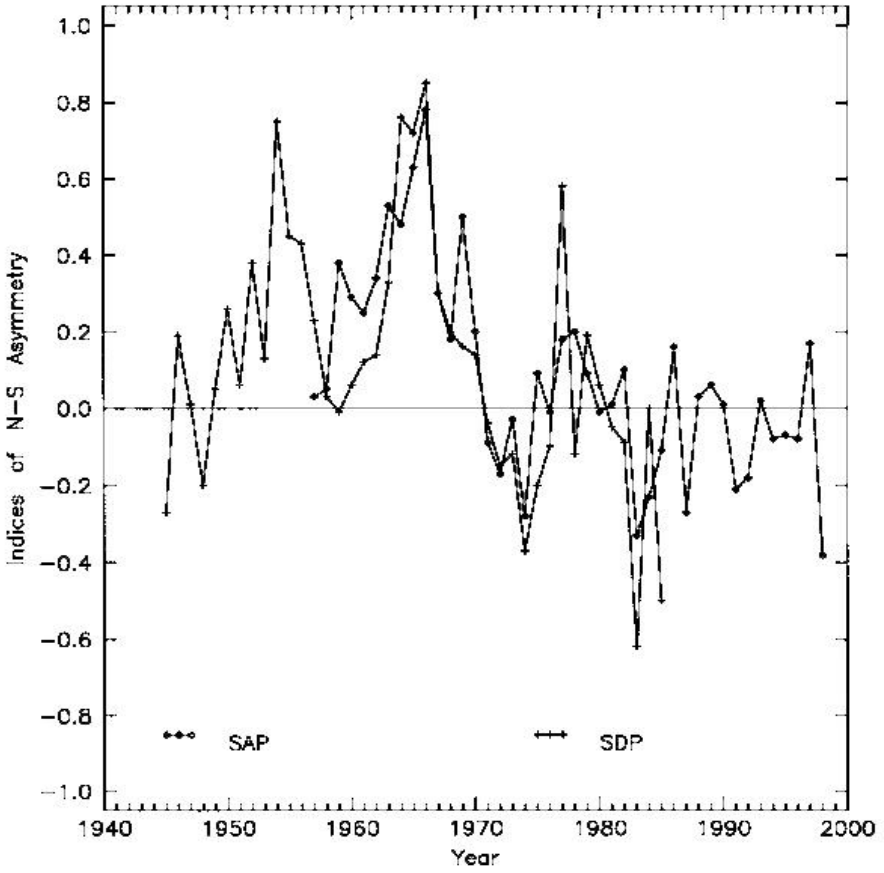


Figure 4. Plot of N-S asymmetry of SAP events versus year (1957–1998).

Verma (2000, Solar Phys., 194, 87)

Verma (2000) estimated NSA indices for solar cycles 18-23 for of SAP events as shown in side figure . In Figure Verma(2000) also plotted NSA indices for solar cycles 18-21 & taken from paper by (Vizoso & Ballester, 1987). This Figure shows that NSA indices dominates in northern hemisphere during solar cycles 18-20 and shift to southern hemisphere in solar cycles 21-23. Verma (2000) results confirm the previous prediction of Verma(1992) that NSA Will be southerly dominated during solar cycles 22nd , 23rd and 24.th

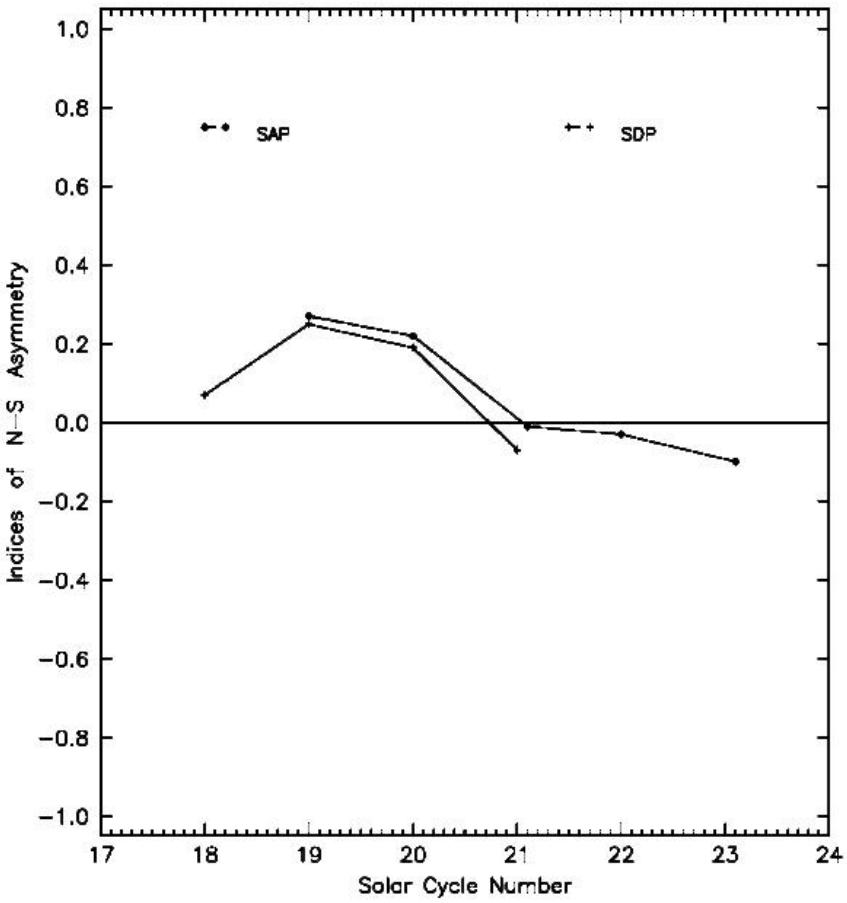


Figure 5. Plot of N-S asymmetry of SAP events versus solar cycle number.

Li, K. J. Et al (2002, A&A, 383, 648)

Li, et al (2002) investigated using power spectrum technique & calculating the actual probability of the dominant hemisphere of solar activity features in each of solar cycles 12-22. Li et al(2002) attempted to demonstrate that a long characteristic time scale, about 12-cycle is possible and support work of Verma(1992, 93).

- **Li et al (2002) used following set of data :**
- **Features Period (SC)**

Sunspot groups:	12-23
Sunspot area	12-23
relative spot no.	10-22
Flare Index	17-23
Number SD	17-21

SC: Solar Cycles

SD: Sudden disappearance

Joshi and Joshi (2004, Solar phys., 219, 343)

Joshi and Joshi (2004) Calculated SXR flares index for period of 1976 -2003 or 21st to 23rd solar cycles as shown in figure. From data set we have calculated yearly NSA indices for SXR flares. We again estimated NSA indices for solar cycles 21-23 and found that NSA indices favor southern hemisphere during solar cycles 21- 23.

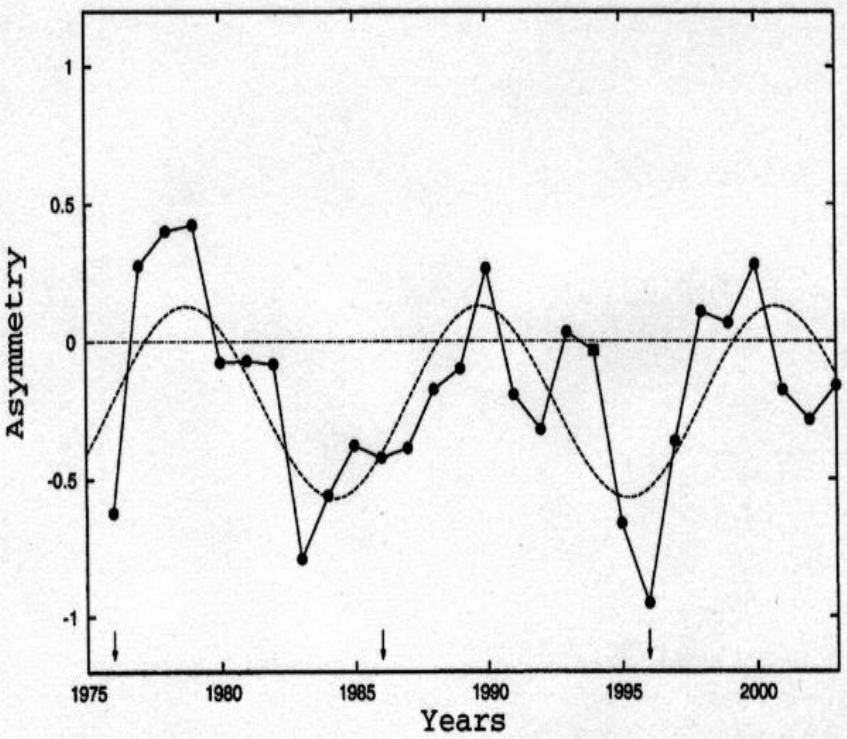


Figure 4. Yearly N–S asymmetry index of FI_{SXR} during 1976–2003. Highly significant asymmetry values with $p \geq 99.5\%$ are marked with *circles*, otherwise *squares* are drawn. The *dashed line* corresponds to the fitted sinusoidal curve with a period of eleven years. *Downward arrows* indicate solar activity minima.

Carbonell, M et al (2007, A&A, 476, 951)

Many studies of the NSA indices of solar activity phenomena and its features have been performed. However, most of these studies do not consider whether or not the asymmetry of the time series under consideration is statistically significant. If the asymmetry is statistically insignificant, any study about its behaviour is meaningless. Carbonell et al (2007) presented a very good statistical estimate formula which may used to check statistical validity of NSA of solar features. Now this formula suggested by Carbonell et al(2007) is widely used by researcher to check statistical significance of estimated NSA for solar phenomena.

Verma(2009, ASPCS, 416, 483)

Verma(2009) used sunspot area: 1821-2008(solar cycles 6-24) ; sunspot count: 1833-1877, solar flare index (SFI): 1936-2006, SXR flares index 1976-2003 and solar active prominence(SAP): 1957-1998 to estimate NSA indices on yearly basis and solar cyclic basis. The period for the all sets of data is not the same.

The N-S Asymmetry of the five solar phenomena is calculated using following formulae:

$$\text{Asymmetry (A)} = \frac{N - S}{N + S}$$

Where N is number of events in solar north hemisphere and S is the number of events in the south hemisphere.

Verma(2009, ASPCS, 416, 483)

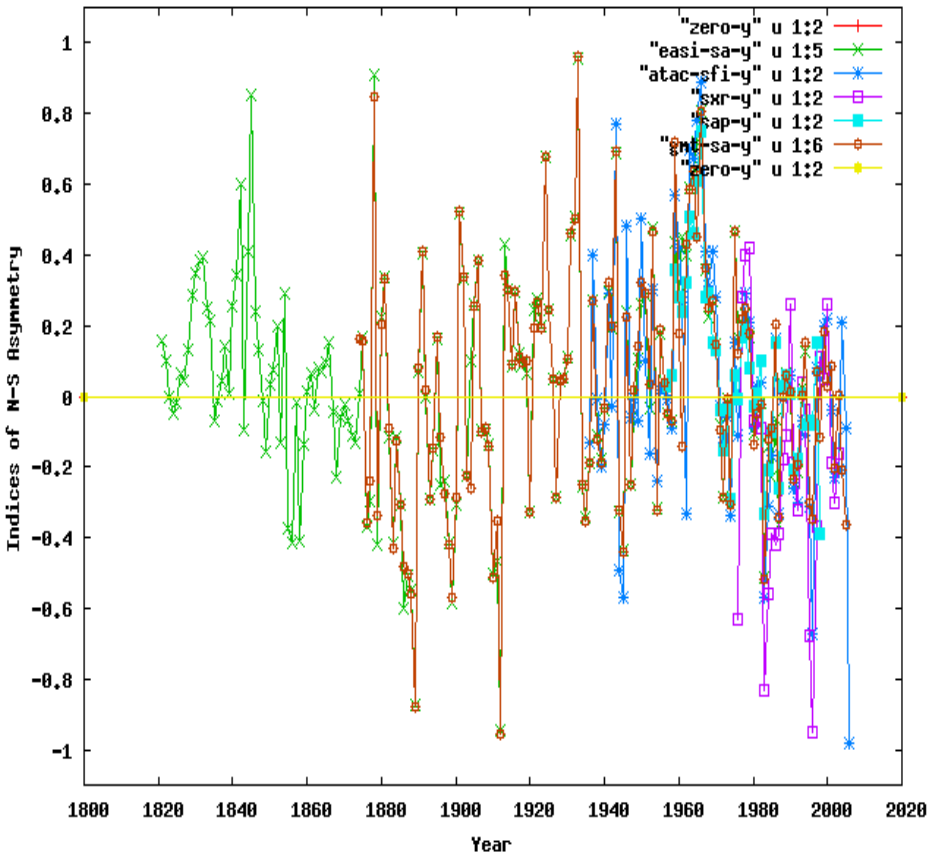
Verma(2009) carried out detailed study of NSA indices of various solar phenomena e.g. sunspot area:1821-2008, sunspot count:1833-1877, solar flare index:1993-2006, SXR flares: 1976-2003 and solar active prominence (SAP): 1957-1998 . The source and period of these data is shown in side Table

- **Table 1. Types of Solar Phenomena and Their References**

Solar Phenomena	Period	References
spot areas	1821-1994	Nagovitsyn etal (2004)
spot areas	1832-1871	Wolbach (1962)
spot areas	1874-2008	Greenwich data
spot count	1833-1877	Newton & Milson (1955)
Flares index	1936-1993	Atac & Ozguc (1996)
Fares index	1994-2006	ftp.koeri.boun.edu.tr
SXR flares	1976-2003	Joshi & Joshi (2004)
SAP data	1957-1998	SGD

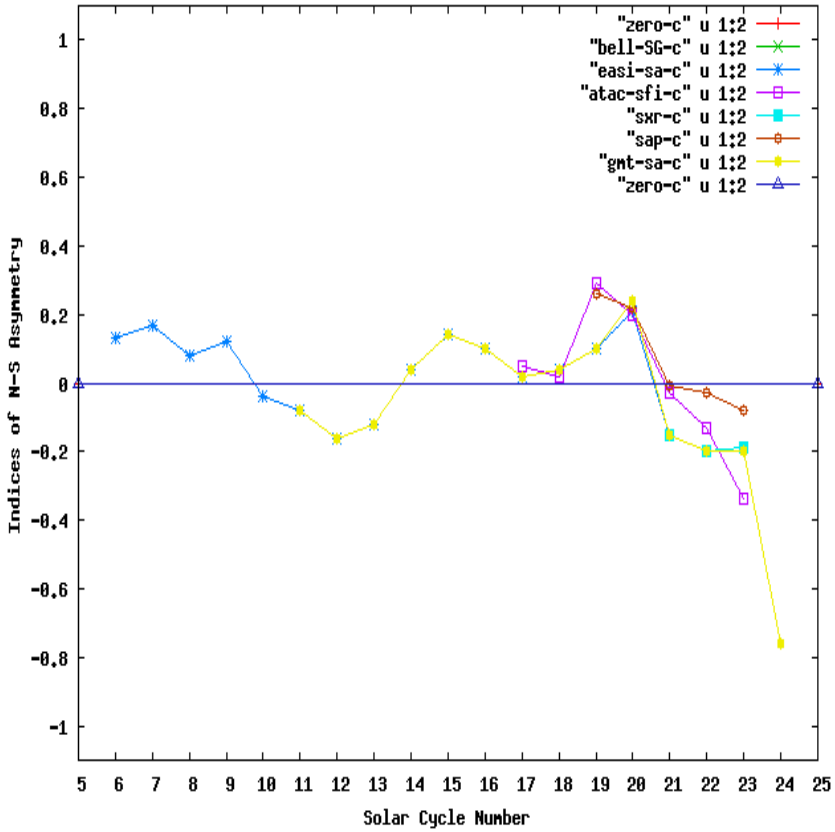
Verma (2009, ASPCS, 416, 483)

Verma(2009) carried out detailed study of NSA indices for various solar phenomena. The solar phenomena includes sunspot area: 1821-2008), sunspot count: 1833-1877, solar flare index:1993-2006, SXR flares: 1976-2003 and SAP: 1957-1998. The plot Year versus NSA indices of various solar phenomena shown in side figure.



Verma (2009, ASPCS, 416, 483)

Verma(2009) estimated solar cyclic mean value of NSA indices for sunspot area, sunspot count, solar flare index, SXR flare index and SAP index for various period mentioned earlier. Figure shows plot of solar cycle number versus NSA indices and also show that solar cycle 21, 22 & 23 are southern dominated. Initial NSA index for solar cycle 24 indicate southern domination.



Verma (2009, ASPCS, 416, 483)

Verma(2009) studied data for period of 6-23 solar cycle using five solar phenomena: Sunspot area, sunspot group, solar flare index, SAP and SXR flare index. This study also show that NSA may have period of 11 solar cycles (~ 110 years) as earlier reported by Duchilev (2001, SP, 199, 211) and not the 12 solar cycles as reported by Verma (1992, 1993). Verma (2009) brief findings were as under:

- **Solar Cycles 6-9 North domination 4 solar cycles**
- **Solar Cycles 10-13 South domination 4 solar cycles**
- **Solar Cycles 14-20 North domination 7 solar cycles**
- **Solar Cycles 21-23 South domination 3 solar cycles**
- **Solar Cycle 24th South domination in progress**

From the present study we have also found that the NSA index during 21st , 22nd and 23rd solar cycles are southern dominated as earlier reported by Verma (1992). The first year of solar cycle 24th (2008) also show southern domination and support result of Verma(1992).

Lin, K.J. et al (2009, SP, 254, 145)

Lin et al (2009) using new index, the cumulative difference of sunspot activity in the northern and southern hemispheres, respectively, is proposed to describe the long-term behaviour of the NSA of sunspot activity and to show the balance (or bias) of sunspot activity in the two solar hemispheres on a long-term scale. Sunspot groups and sunspot areas from June 1874 to January 2007 are used to show the advantage of the index. According to Lin et al (2009) the NSA index clearly shows a long-term characteristic time scale of about 12 cycles in the NSA of sunspot activity. Sunspot activity is found to dominate in the southern hemisphere in cycle 23, and in cycle 24 it is predicted to dominate still in the southern hemisphere. This work of Lin et al (2009) clearly support the result of Verma(1992)

Present Work

In the present investigation we have used N-S Asymmetry data for the period of 1821-2015 or solar cycles 6 to 24. The period for the all sets of data is not the same. The solar phenomena considered for this study are as under:

1- Sunspot area (1821-2015)

2- Solar Flares Index (1936-2014)

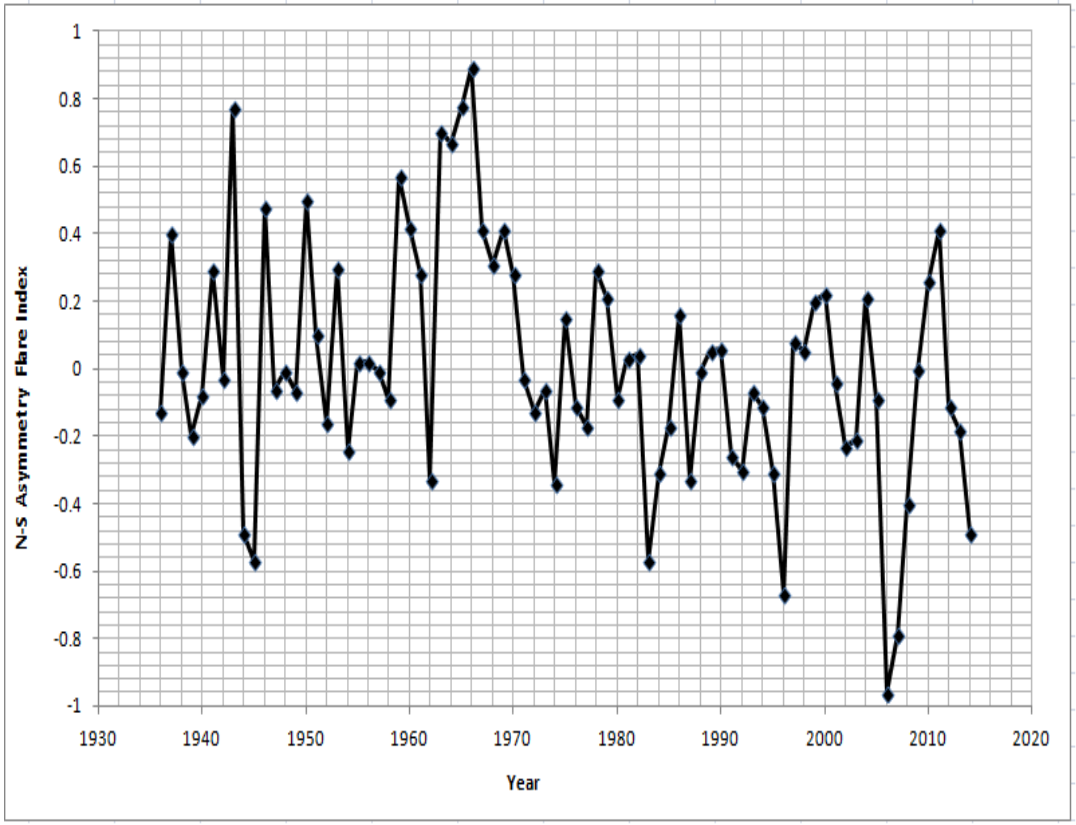
The N-S Asymmetry of the two solar phenomena is calculated using following formulae:

$$\text{Asymmetry (A)} = \frac{N - S}{N + S}$$

Where N is number of events in solar north hemisphere and S is the number of events in the south hemisphere.

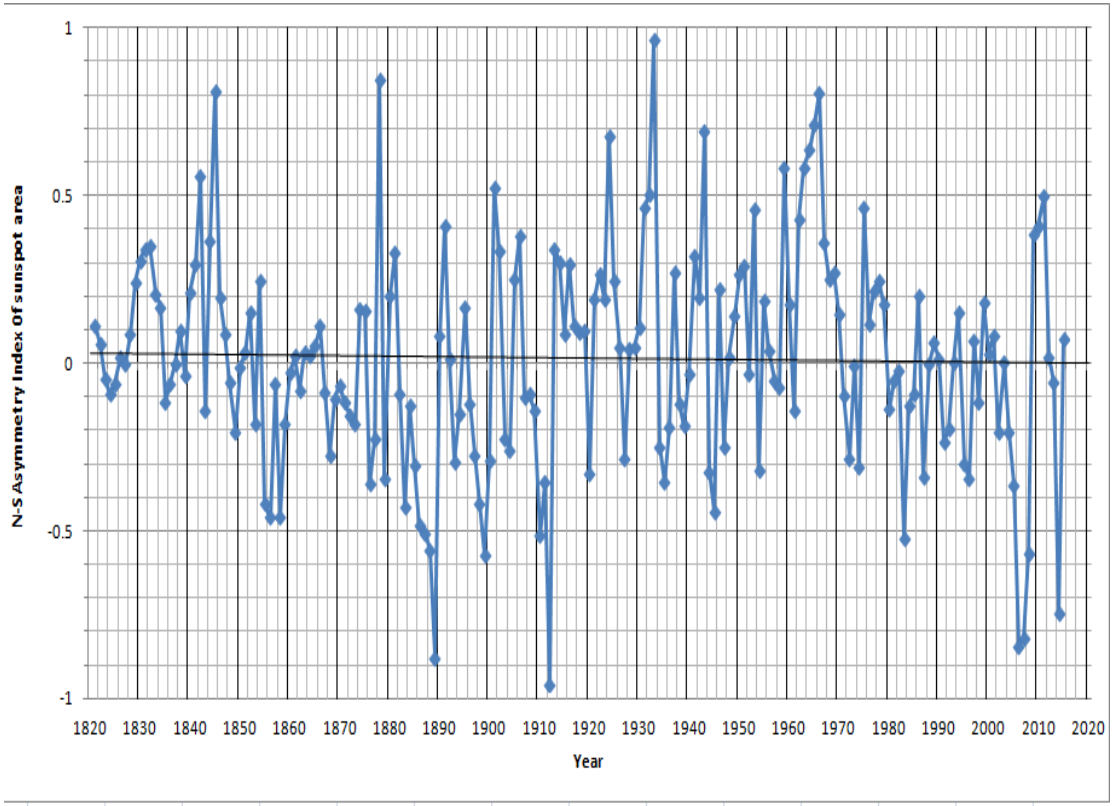
Present work-continued

The yearly NSA indices of solar flares index(SFI) for period 1976-2014 are calculated. The NSA of SFI was earlier published by Atac and Ozguc (1996, SP, 166, 201)for period 1936-1993 is also used in present study. NSA indices for period 1994-2014 is taken from website created by Atac & Atac, Both data are very useful to understand hemispheric NSA of Sun. The side figure shows the plot year versus yearly NSA indices for flare data.



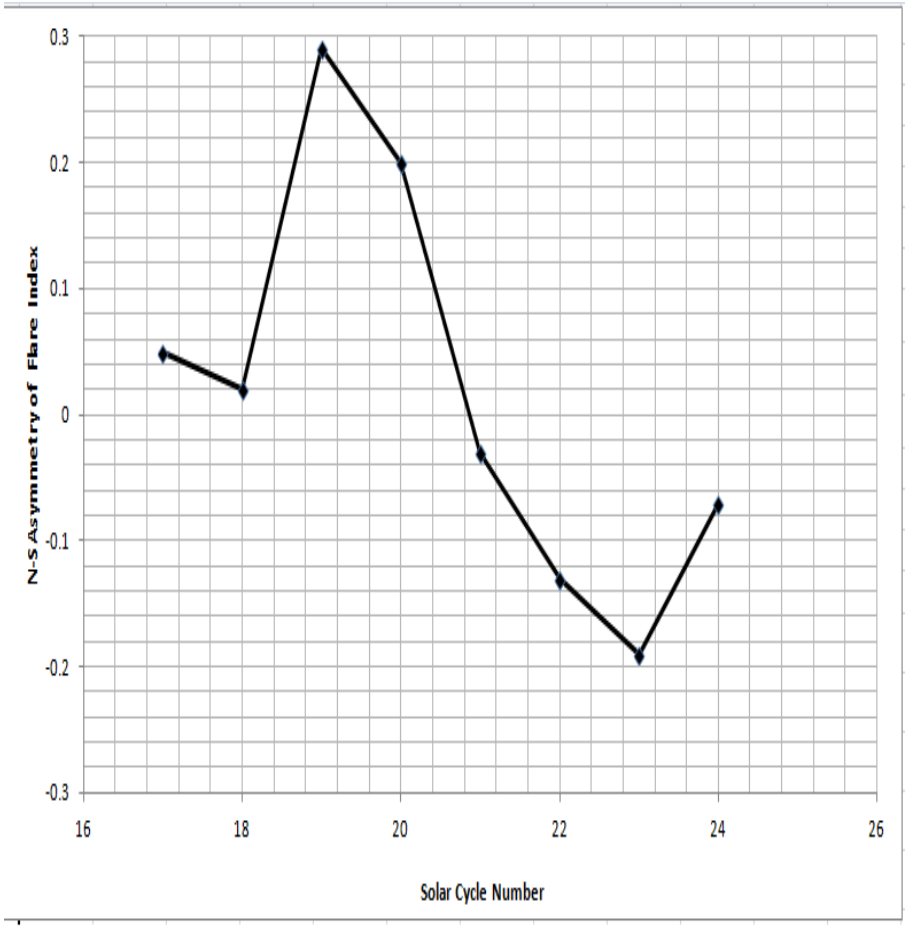
Present Work

In the present investigation we have used sunspots area data (1821-2015) and flare index data (1936-2014) for various solar cycles. In side figure we have shown a plot of Year versus NSA indices for sunspot area 1821-2015.



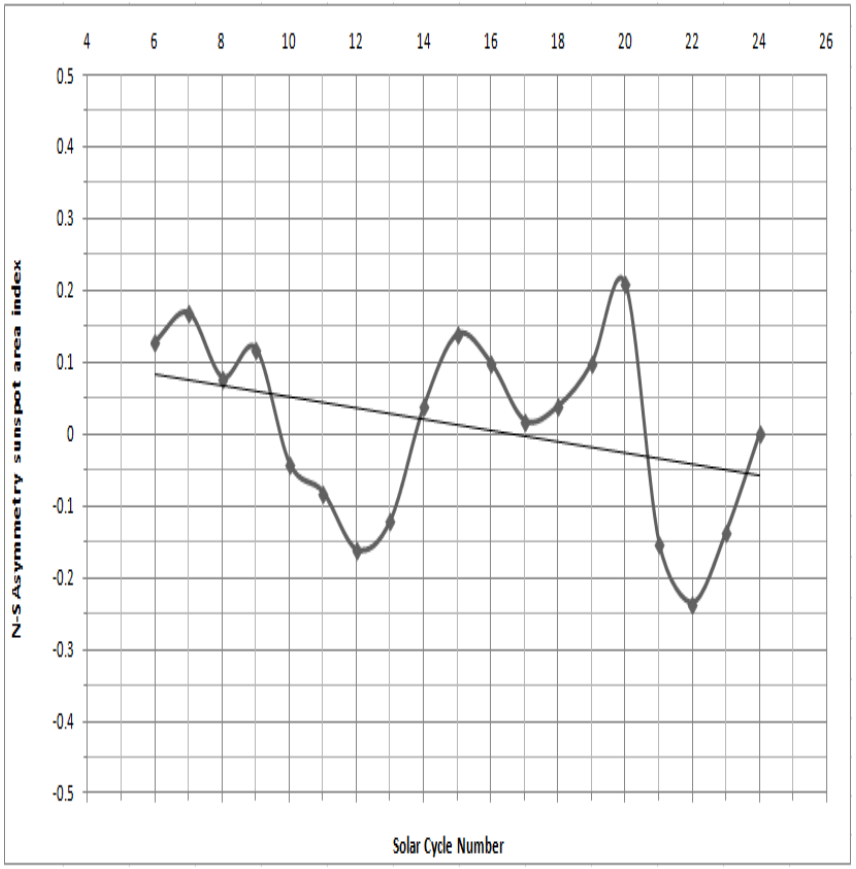
Present Work Continued

From the yearly values of NSA indices for solar flare data we have calculated the solar cyclic mean value of NSA for solar flare data for solar cycle 17-24 (1936-2014) as shown in side figure. From side figure it clear that flare NSA for solar cycle 24 (2008-2014) indicate that NSA indices dominant in southern hemisphere as suggested by Verma (1992).



Present Work Continued

From Yearly value of NSA of Sunspot area data we estimated cyclic mean of NSA for sunspot area. In side figure we have plotted Solar cycle Number versus NSA index of sunspot area. This figure shows that NSA in solar cycle 24 is still dominate in southern hemisphere as predicted by Verma (1992). The solar cycle 24 has still period3-4 years & thus NSA indices will known after 3-4 years.



Present Work: Conclusions

The present study show that the NSA has a period of ~11 solar cycles and following this trend we are of the view that the NSA of 24th solar cycle may be southerly dominated based on data for years 2008-2015 and NSA may shift to northern hemisphere during solar cycle 25th as earlier suggested by Verma (1992).

This study further show that the NSA index were northern hemisphere dominated during solar cycles 6-9 (4 solar cycle) and than shifted to southern hemisphere for solar cycles 10-13 (4 solar cycles). From solar cycles 14-20 (7 solar cycles) the NSA favor northern hemisphere and than NSA shifted to southern hemisphere for solar cycles 21-24 (4 solar cycles). The solar cycle 24th is still in progress and further last for another 3-4 yrs.

Present work: Conclusions

The dominance in any of hemisphere indicate excess flux /energies etc. in that particular hemisphere. If the energies are linked to the mass this means that the dominant hemisphere is more massive than other one which may lead to oscillatory behavior of Sun. This study may be useful to understand this type of problem related with magnetic Sun. The result of this study may be helpful to understand long-term helioseismic phenomena and dynamo models of the Sun which are based on the magnetic fields related to solar active